SCIENCE

A WEEKLY JOURNAL DEVOTED TO THE ADVANCEMENT OF SCIENCE, PUBLISHING THE OFFICIAL NOTICES AND PROCEEDINGS OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

FRIDAY, MARCH 22, 1907

CONTENTS

MSS. intended for publication and books, etc., intended for review should be sent to the Editor of SCIENCE, Garrison-on-Hudson, N. Y.

THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

CLOCKS—ANCIENT AND MODERN[1]

Mr. Chairman, Ladies and Gentlemen:

To those who have never had an opportunity to acquaint themselves with the history of the development of the modern clock, I wish to say that no attempt will be made to trace out that development. Time will not permit, as those familiar with the subject well know. I only wish to call to your attention a few points that I hope may be of general interest.

In Nepal, a small independent state situated on the northeastern frontier of Hindustan, there is still practised what is one of the crudest and probably earliest methods of measuring time. A copper vessel with a small hole in the bottom floats on water, sinks and fills sixty times a day. Each time it fills a gong, or ghari, is struck, in progressive numbers from dawn to noon; after noon the first gong struck indicates the number of gharis which remain of the day until sunset. Day is considered to begin when the tiles of a house can be counted or when the hairs on the back of a man's hand can be discerned against the sky. The day is divided into 60 gharis of 24 minutes each, each ghari into 60 palas and each pala into 60 bipalas.

Leaving India for Sumatra and stepping aboard a Malay proa we should there find, floating in a bucket of water, a cocoanut shell having a small perforation, through

[1] Address of the retiring vice-president of Section A, American Association for the Advancement of Science.

which the water by slow degrees finds its way into the interior. When the shell fills and sinks, the man on watch calls the time and sets it afloat again.

The gradual development through untold ages of the floating copper vessel has given us our finest astronomical clocks of to-day, and similarly the floating cocoanut shell may be considered the simplest form of a marine chronometer.

If now we visit the Chinese Empire we find in use there also the water clock, but instead of the water flowing into a vessel through a small hole in the bottom, it flows out of the hole. In attempting to calibrate such a vessel so that any given portion of the whole time required to empty it might be determined, it is at once noticed that when the vessel is nearly full the water flows out more rapidly than when it is nearly empty. The difficulty here presented is most easily overcome by keeping the vessel filled with water when the flow will be uniform, and catching the discharged water in a cylindrical vessel in which the surface of the water will rise equal distances in equal times. Chinese writers ascribe the invention of this instrument, called a clepsydra, to Hwang-ti, who lived more than twenty-five centuries before our era. About fourteen centuries later Duke Chau introduced a float upon the surface of the water in the final cylinder by means of which an indicator was made to travel over an adjacent scale as the water rose in the cylinder, thus allowing the indications of the instrument to be perceived at a greater distance.

These instruments that have just been described may be called artificial timekeepers, and are used primarily to subdivide the day, while the sundial of equal antiquity with the others may be called a natural timekeeper, as it gives a means of determining day after day a particular time of day, such as apparent noon.

The earliest mention of a sundial is found in Isaiah 38: 8, in connection with the promise of the Lord to add fifteen years to the life of Hezekiah who lived about 2,600 years ago. "And this shall be a sign unto thee from the Lord, that the Lord will do this thing that he hath spoken; behold, I will bring again the shadow of the degrees, which is gone down in the sundial of Ahaz, ten degrees backward. So the sun returned ten degrees, by which degrees it was gone down."

Of the nature of this sundial nothing is said, nor is there found any description of such an instrument until 350 years later, when we find the sundial of the Chaldean priest Berosus, who lived in the time of Alexander the Great and his immediate successors.

This consisted of a hollow hemisphere placed with its rim perfectly horizontal, and having a bead fixed at its center. So long as the sun remained above the horizon the shadow of the bead would fall on the inside of the hemisphere, and the path of the shadow during the day would be approximately a circular arc. This arc, divided into twelve equal parts, determined twelve equal intervals of time for that day. Now supposing this were done at the time of the solstices and equinoxes, and on as many intermediate days as might be considered sufficient, and then curve lines drawn through the corresponding points of division of the different arcs, the shadow of the bead falling on one of these curve lines would mark a division of time for that day, and thus we should have a sundial which would divide each period of daylight into twelve equal parts. These equal parts were called *temporary hours;* and since the duration of daylight varies from day to day, the temporary hours of one day would differ in length from those of another. Dials of this form were still used by the Arabians a thousand years ago,

and about 1750 four such were found in Italy.

The introduction of the sundial into Greece is generally fixed by historians in the latter part of the sixth century B.C. At that time the instrument seems to have been a very crude one, consisting merely of a pillar without any graduated dial by means of which the day could be divided into a number of equal parts. The length of the shadow determined the time for certain regular daily duties, as a shadow six feet long might indicate the time for bathing, and one twelve feet long that for supper.

As civilization advanced and the needs of the people required more accurate measures of time, the sundial was developed. We have already mentioned the sundial of Berosus, about 350 B.C., by means of which each day from sunrise to sunset was divided into twelve equal parts, that is provided the sun was visible all day long.

As the sundial could not be used indoors or on cloudy days, as soon as the Grecian life became complex enough to need a timepiece under such circumstances, this demand was met by the clepsydra. The time of its introduction is not definitely known, but the familiar references of Aristophanes show its use to have been common about 430 B.C., while no mention is made of it by Herodotus, whose history ends fifty years earlier.

A passage in Aristotle gives some idea of the early form of the clepsydra: it was a spherical bottle with a minute opening at the bottom and a short neck at the top into which the water was poured, and by closing which the flow of the water could be stopped. This form of clepsydra became a necessary adjunct of all courts of justice, and the number of gallons of water that a lawyer was allowed for his speech gave some indication of the importance of the trial. In fact, the word ὕδωρ became a synonym for time. We find Demosthenes charging his opponent with talking 'in my water'; and on another occasion he shows the value he attached to the time allotted him by turning to the officer, when interrupted, with a peremptory 'You there! stop the water!' reminding one of the 'take out time' of our modern football contests.

The first timepiece of the Romans seems to have been the watchman, who, from the Senate House, called forth noon as soon as he caught sight of the sun between the Rostra and the Græco-Statis. From the same point he watched the declining sun and proclaimed its disappearance. This custom was probably instituted towards the close of the fifth century B.C. According to Pliny the first sundial was set up in Rome about 290 B.C. About thirty years later Consul Valerius Messala erected at Rome a sundial which was captured at Catania in Sicily. This instrument was not a mere gnomen such as was introduced three centuries earlier into Greece, but was the result of Grecian science and genius, constructed for a particular latitude, that of Catania 5° south of Rome. For a hundred years this sundial supplied the needs of the Romans for a timepiece, although it was constantly in error. Finally, in 164 B.C., Marcius Phillippus set up near the dial of Catania, one constructed for the latitude of Rome, and Rome then possessed her first accurate timepiece; and during the time of Plautus the use of sundials became common, as is evidenced by the following quotation:

When I was young, no time-piece Rome supplied,
But every fellow had his own—inside;
A trusty horologe, that—rain or shine—
Ne'er failed to warn him of the hour—to dine,
Then sturdy Romans sauntered through the Forum,
Fat, hale, content; for trouble ne'er came o'er them,

But *now* these cursed dials show their faces,
All over Rome in streets and public places;
And men, to know the hour, the cold stone question,
That has no heart, no stomach, no digestion,
They watch the creeping shadows—daily thinner—
Shadows themselves, impatient for their dinner.
Give me the good old time-piece, if you please,
Confound the villain that invented these!

As in Greece so in Rome, the clepsydra followed in the wake of the sundial, and as in the case of the sundial, Grecian science and genius had by this time produced a much more perfect instrument than that first used by the Greeks.

In describing the sundial of Berosus, I stated that by it the day was divided from sunrise to sunset into twelve parts, varying in lengths from day to day, called temporary hours. If now the clepsydra and the sundial were to read alike, it was necessary that the hours recorded by the clepsydra should also change from day to day. Various devices were adopted to accomplish this. Further, as the clepsydra could be used throughout the entire day and night, it was necessary to have it record hours of a different length at night from what it did in the day, as each night, *i. e.*, from sunset to sunrise, was divided into twelve hours as well as each day.

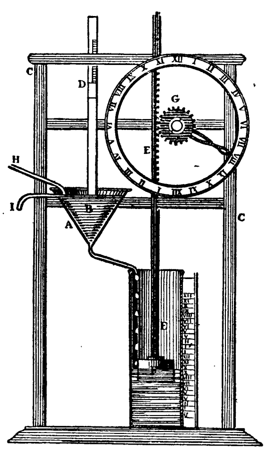


Fig. 1. Early Form of Clepsydra.

Fig. 1 represents an early form of the clepsydra. It consists of an inverted cone *A*, with a small aperture at its vertex. The water is supplied through the pipe *H* and is prevented from rising above a fixed level in *A* by the waste pipe *I*, which carries off the superfluous water. Thus there will be a uniform flow of water from the vertex of the cone into the cylindrical vessel and the cork *F* will rise uniformly, communicating its motion through the rod *E* to the hand *G*, which indicates the hours on the dial. In order to produce a change in the rate of flow of the water from the conical vessel, as is necessary in having the hand indicate hours of different length from day to day, a solid cone *B*, similar to *A*, was plunged into the hollow one, and its position for any given day or night was indicated by the coincidence of a particular one of the adjusting marks on the stem *D* with the top cross-piece of the frame *C*.

A later form of clepsydra, attributed to Ctesibius, who lived during the latter part of the third century B.C., is shown in Fig. 2. *A* is the end of a tube over which an image stands, which is connected with a full reservoir, and from the eyes of which, considered as invariable apertures, the water continually flows or drops in a regulated manner into it; this tube conveys the water into

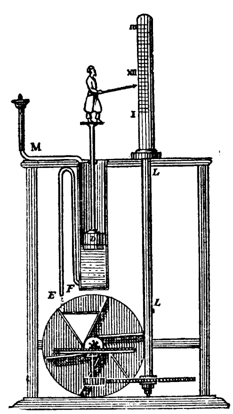


Fig. 2. Clepsydra of Ctesibius.

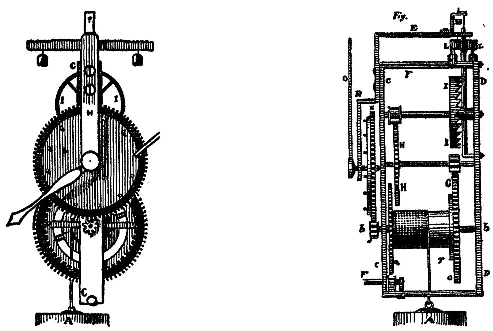
the top of the cylindrical vessel *BCDF*, which gradually fills, the cork *D*, with its attached pillar *C*, rising at the same time. On the top of this pillar is an image holding an index which points to the divisions on the large column above. Now when the water rises in the cylindrical vessel it also rises in the small tube *FB*, which constitutes one leg of a syphon; consequently, when the small tube fills and the index has mounted to the top of the large column, the water flows over the bent part *B* of the syphon and the vessel is emptied into one of the six troughs of the waterwheel *K*, which is thus turned one sixth of a revolution, and the column, by means of the gearing shown in the figure, 1/365 of a revolution, during which time the image falls with its index to the bottom of the column, to be ready for the next day. There are ruled around the large column twenty-five lines properly sloped with respect to each other, so that the index may indicate the hour on any day of the year.

For the next fifteen centuries or more after the introduction of this clepsydra of Ctesibius, sundials and clepsydras were the timekeepers of mankind. These were then gradually supplanted by weight clocks.

I am not able to give the date of the manufacture of the first clock composed of an assemblage of wheels actuated by a suspended gravitating body and controlled by a regulator of some determined shape and dimensions, *i. e.*, a regulated machine for measuring time without the assistance of water.

There may be seen at the South Kensington Museum an old clock movement, now controlled by a pendulum, which was removed about seventy years ago from a clock in Wells Cathedral and which is said to have been built by Peter Lightfoot, about 1335, for the church of Glastonbury Abbey, from which it was removed to Wells Cathedral in the reign of Henry VIII., where, I believe, the dial and its accessories may now be seen. In addition to indicating the time, this clock was intended to indicate the age of the moon and to show its phase. Also it caused a man to strike the quarter hours with his feet on two little bells, and the hours on another bell before him with a battle-axe that is in his hand. It also set in motion four equestrian knights equipped for a tournament. If the date given for the clock is correct the figures operated in connection with it are hardly the original ones. One of the knights is painted in the civil costume of the seventeenth century.

About 1360 there was erected in the tower of the palace of Charles V. of France a clock constructed by Henry de Vick, of Würtemberg. This clock was made for the simple purpose of telling the time of day and was not expected to perform the numerous feats that were so frequently required of clocks in earlier days, and may be taken as a type of the earliest clock movements.



Front view. Side view.

FIG. 3. Ancient Clock by Henry de Vick.

From Fig. 3, giving both a front and a side view, the operation of the clock may be clearly understood. The motion of the falling weight *A* is transmitted by means of the wheels *G*, *e*, *H* and *g* to the wheel *I*; this last wheel, by giving the pallets or short levers, *h*, *i*, each a push alternately by two teeth, at opposite sides of its cir-

cumference, and moving in opposite directions, one forward and the other backward, gives a vibratory motion to the vertical arbor *K*, and as the regulator or balance was fixed on this arbor, it was thus made to vibrate backwards and forwards at every push of the escapement wheel upon the pallets, the period of the vibration being regulated by the position of the small weights *m*, *m* on its arms. Thus the whole duration of a vibration was the measure of time, and the wheels and pinions were employed first to transmit the maintaining power to the balance, and secondly to number the vibrations and indicate them in visible form by a hand *O* on a dial plate.

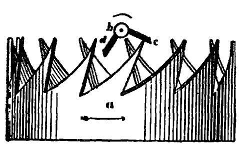


FIG. 4. View of de Vick's Escapement Wheel from above.

Fig. 4 gives a view of the escapement wheel looking from above. The pallets were placed at about 90° from each other on the arbor or verge of the balance, so that when one of them was parting with its tooth of the escapement wheel, the other was in a situation to receive the opposite one immediately, but the motion of the verge will not be at once reversed. The escape wheel will recoil until the impetus of the balance is exhausted.

The substitution of the main spring for a large heavy body as a first mover constituted a second era in modern horology, from which we may date the origin of the fusee, or mechanism for equalizing the variable power of a coiled spring.

While the date at which the first portable clock was made may not be definitely stated, it was certainly as early as 1525, as the Society of Antiquaries in England has in its possession one made in that year by Jacob Zech at Prague, the inventor of the fusee. Its construction differs materially from that of De Vick's clock only in that it has a spiral spring with a fusee instead of the driving weight.

Such was the state of clockwork when Galileo, the celebrated philosopher and mathematician, while watching the vibrations of the great bronze lamp swinging from the roof of the cathedral of Pisa in 1583 observed that, whatever the range of its oscillations, they were invariably executed in equal times. Because of this isochronal property of a vibrating suspended body the pendulum was introduced as the regulator of clockwork, thus inaugurating the third era in the development of the modern clock.

The honor of being the first to apply a pendulum as a regulator of clockwork is claimed for several clock-makers.

The earliest of these is, I believe, Richard Harris, who is said to have made a pendulum clock for St. Paul's Church, Covent Garden, in 1641. Vincent Galileo claims to have applied his father's discovery to the construction of a pendulum clock in 1649, but does not seem to have made the fact public until after Huyghens in 1657 presented to the States of Holland a clock controlled by a pendulum, claiming for himself the invention of this form of control. Certain it is that Huyghens gave much study to the mathematical theory of the pendulum, and proved that in order that pendulum vibrations of different lengths should be strictly isochronal, the pendulum should vibrate between cycloidal checks. Such an arrangement he introduced into his clock of 1657, which also contained the famous Huyghens loop in connection with the winding apparatus.

With the verge escapement, Fig. 4, the one in use when the pendulum was applied to clockwork, and which required a long arc of vibration for the escapement of the

escapement wheel, the deviation of the circular arc described by an ordinary pendulum from the theoretical cycloidal arc was, of necessity, taken into account. With the introduction of the anchor or recoil escapement, Fig. 5, invented by Dr. Hooke in about 1675, the long swing of the pendulum was obviated and the cycloidal cheeks were found to be more detrimental than advantageous.

The expansion of metals by heat has been known ever since the middle of the seventeenth century, and early in the eighteenth George Graham set himself the task of making a clock pendulum such that the distance between the center of oscillation and the center of suspension would be independent of the temperature. I quote from his paper 'A Contrivance to avoid Irregularities in a Clock's Motion by the Action of Heat and Cold upon the Pendulum,' communicated to the Royal Society in 1726:

Whereas several who have been curious in measuring time have taken notice that the vibrations of a pendulum are slower in summer than in winter, and have very justly supposed this alteration has proceeded from a change of length in the pendulum itself, by the influence of heat and cold upon it, in the different seasons of the year; with a view, therefore, of correcting, in some degree, this defect of the pendulum, I made several trials, about the year 1715, to discover whether there was any considerable difference of expansion between brass, steel, iron, copper, silver, etc., when exposed to the same degree of heat as nearly as I could determine, conceiving it would not be very difficult, by making use of two sorts of metals, differing considerably in their degrees of expansion and contraction, to remedy, in great measure, the irregularities to which common pendulums are subject. But although it is easily discoverable that all these metals suffer a sensible alteration of their dimensions by heat and cold, yet I found their differences in quantity from one another were so small, as gave me no hopes of succeeding this way, and made me leave off prosecuting this affair any further at that time. In the beginning of December, 1721, having occasion for an exact level, besides other materials I made trial of, quicksilver was one; which, although I found it was by no means proper for a level, yet the extraordinary degree of expansion that I observed in it when placed near the fire, beyond what I had conceived to be in so dense a fluid, immediately suggested to me the use that might be made of it by applying it to a pendulum. In a few days after I made the experiment, but with much too long a column of quicksilver, the clock going slower with an increase of cold, contrary to the common pendulum; however, it was a great confirmation of the advantage to be expected from it, since it was easy to shorten the column in any degree required.

As his first jar was too long, so his second was too short, but by June 9, 1722, he was ready to test the running of his mercury pendulum clock with one regulated by an uncompensated pendulum. He says:

For the first year I wrote down every day the difference between the two clocks, with the height of the thermometer, not omitting the transits of the stars as often as it was clear. The result of all the observations was this, that the irregularity of the clock with the quicksilver pendulum, compared with the transits of the stars, exceeded not, when greatest, a sixth part of that of the other clock with the common pendulum; but for the greatest part of the year, not above an eighth or ninth part, and even this quantity would have been lessened had the pillar of mercury been a little shorter, for it differed a little the contrary way from the other clock, going faster with heat, and slower with cold; but I made no alteration in length to avoid an interruption of the observations.

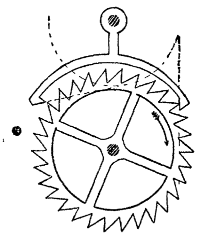
A few years afterward John Harrison brought out his gridiron pendulum composed of four brass and five steel rods, so constructed that the expansion of the steel rods tended to lower the pendulum bob while the expansion of the brass ones tended to raise it.

Another form of compensated pendulum that has found favor is the zinc-tube pendulum, in which the zinc tube surrounds a rod of steel and is itself surrounded by a tube of steel. Here the zinc tube fulfils the purpose of the brass rods in the gridiron pendulum. At present at least one

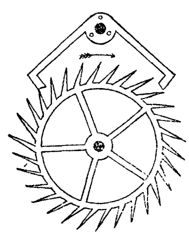
firm of clock manufacturers is using invar or nickel steel for its pendulum rods.

Attempts have also been made to compensate a pendulum to avoid changes in the rate due to changes of the barometer. At Greenwich this is accomplished by attaching a magnet to the end of the pendulum and causing a second magnet supported below the pendulum to approach or recede from the pendulum with changes of the barometer. This second magnet increases the acceleration due to gravity to a greater or less degree as it approaches or recedes from the pendulum.

The most satisfactory way, however, of freeing a clock rate from variations due to changes of temperature and pressure is to enclose the clock in an air-tight glass case kept in a room of constant temperature. A number of observatories now keep their standard clocks under such conditions.



Anchor or Recoil Escapement.



Dead-beat Escapement.

Fig. 5.

Another improvement in the manufacture of clocks was accomplished by Graham in the introduction of the dead-beat escapement.

In Fig. 5 are shown both the anchor or recoil escapement and the dead-beat escapement. In the first, shown on the left, the pendulum moving to the left has just escaped a tooth at the left-hand pallet and allowed a tooth to fall on the right-hand one. The pendulum, however, still continues its swing to the left, and in consequence the pallet pushes the wheel back, thus causing the recoil that gives the name to the escapement. It is only after the pendulum comes to rest and begins its excursion the other way that it gets any assistance from the wheel, and the difference between the forward motion of the wheel and its recoil forms the impulse. In the right-hand figure, the pendulum moving to the right has just escaped a tooth from the right-hand pallet while another has fallen upon the left-hand one. As the pendulum continues its motion towards the right, the left hand-pallet slides over the point of the tooth, but there is no recoil, as the 'dead' face, as it is called, is the arc of a circle whose center is the point about which the anchor turns. As the pendulum returns towards the left, the tooth traverses the 'dead' face in the opposite direction, and immediately upon leaving this face it passes to the 'impulse' face, and while passing along this face gives the impulse to the pendulum.

The great advantage of the dead-beat escapement over the anchor or recoil type is that, although a slight increase of force on the escapement wheel increases the arc of the pendulum, it does not sensibly increase the time, while the time does sensibly increase with the recoil escapement.

At about this time also, Mudge introduced the gravity escapement. With all the previous escapements the impulse was given to the pendulum by the driving weight acting through the train so that any irregularities in the train would cause a variation in the impulse. With the gravity escapement a weight is raised by the train and the falling of this weight gives the impulse to the pendulum. We thus have a uniform impulse at each oscillation due to the falling of a weight through a fixed distance. Simple and elegant as is this theory, the application of it gave a great deal of trouble and all gravity escapements were regarded with suspicion, as having a tendency to trip, until Mr. Denison designed

the double three-leg one for the great clock at the Houses of Parliament about fifty years ago. Incidentally, it might be mentioned that this Westminster clock has turned out to be the finest timekeeper of any public clock in the world. The original specifications required that the clock should be guaranteed to perform within a margin of a minute a week, which caused the leading clock-makers of England to decline to bid for the work. However, under Mr. Denison's supervision the clock was built by Mr. Dent, and from reports of the Astronomer Royal, who receives at Greenwich two signals a day from this clock, sent automatically, its error is rarely over a second a week.

The Denison gravity escapement is shown in Fig. 6. This escapement con-

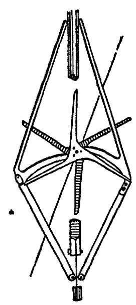


FIG. 6. Denison Gravity Escapement.

sists of two gravity-impulse pallets pivoted as nearly as possible in a line with the bending point of the pendulum spring and touching the pendulum near the bottom of the figure. The locking wheel is made up of two thin plates having three long teeth or 'legs' each. These two plates are squared on the arbor a little distance apart, one on each side of the pallets. Between them are three pins which lift the pallets. In the figure, one of the front legs is resting on a block screwed to the front of the right-hand pallet. There is a similar block screwed to the back of the left-hand pallet for the legs of the back-plate, which is shaded in the figure, to lock upon. Projecting inward from each of the pallets is an arm. The tip of the one on the right-hand pallet is just in contact with one of the pins which has lifted the pallet to the position shown. The pendulum is traveling in the direction indicated by the arrow, and the left-hand pallet has just given impulse. The pendulum rod in its swing will push the right-hand pallet far enough for the leg of the front locking plate, which is now resting on the block, to escape, Directly it escapes, the left-hand pallet is lifted free of the pendulum rod by the lowest of the three pins. After the locking wheel has passed through 60°, a leg of the back locking plate is caught by the locking block on the left-hand pallet. As the three-leaved pinion always lifts the pallets the same distance, the pallets in returning give a constant impulse to the pendulum.

About fifteen or twenty years ago the Rieflers, clockmakers of Munich, introduced into their clocks an escapement in which the impulse is communicated to the pendulum through the suspension spring. The pendulum is supported by a rocking frame to which is attached the anchor carrying the pallets which are acted upon by the escapement wheel. Just after the pendulum has passed through its vertical position, the escapement wheel, when released, gives to the supporting frame of the pendulum suspension spring a slight tilt in the opposite direction from that in which the pendulum is moving, thus increasing the tension of the spring due to the swing of the pendulum to one side.

In the next few minutes I wish to consider the accuracy with which our astronomical clocks perform their function.

The earliest star catalogue of precision is that of Bradley and the observations upon which it is based were made about a third of a century after the introduction of the compensated pendulum. In discuss-

ing the performance of his clock, I have used the adopted rates as given by Auwers in his rereduction of Bradley. The monthly means of the rates from July, 1758, to July, 1759, were taken and the difference of each rate from its monthly mean. Then the mean of these differences without regard to sign was taken for each month.

VARIATION OF DAILY RATE OF THREE GREENWICH SIDEREAL CLOCKS

Bradley's Clock			Sidereal Stand. "Hardy"			Sidereal Stand. "Dent"		
Date	Daily Rate	Mean Residual	Date	Daily Rate	Mean Residual	Date	Daily Rate	Mean Residual
1758	s	s	1850	s	s	1900	s	s
July	—0.086	0.060	January	+0.666	0.269	January	+0.280	0.035
August	+0.012	0.079	February	+0.857	0.162	February	+0.196	0.041
September	—0.012	0.077	March	+0.930	0.117	March	+0.170	0.038
October	—0.130	0.166	April	+1.154	0.257	April	+0.134	0.027
November	—0.094	0.127	May	+1.607	0.105	May	+0.078	0.028
December	—0.190	0.096	June	+1.372	0.117	June	+0.022	0.045
1759								
January	—0.264	0.106	July	+1.058	0.202	July	—0.096	0.039
February	—0.343	0.072	August	+0.821	0.104	August	—0.245	0.053
March	—0.449	0.108	September	+1.003	0.087	September	—0.381	0.056
April	—0.310	0.125	October	+1.049	0.120	October	—0.549	0.048
May	—0.322	0.127	November	+1.232	0.063	November	—0.522	0.161
June	—0.439	0.086	December	+1.389	0.187	December	—0.259	0.036
Mean		0.102	Mean		0.149	Mean		0.051

The rates of two other clocks of the Greenwich Observatory were likewise discussed, the standard clock for the year 1850 and that for 1900, the adopted daily rates as published in the annual volumes being used. The first of these was kept in the observing room and thereby subjected to large variations of temperature, while the second, made in 1871 by E. Dent and Company, was fixed to the north wall of the magnetic basement, as in this apartment the temperature is kept nearly uniform. The pendulum of this latter clock is provided with barometric as well as thermometric compensation.

I sought to make a similar comparison for the clocks of the other large observatories, but soon found that the information concerning the performance of the various clocks was given in such a form that it was in almost every case either impossible or extremely laborious to secure the desired result. However, there are two well-known clocks which should be mentioned in this connection, and in conclusion I will give some hitherto unpublished data concerning the clock with which I have been working during the past three years.

Probably no clock has had its rate more thoroughly discussed than Hohwü No. 17, the standard clock of the observatory at Leiden.

It was set up in the transit room in 1861 and in December, 1898, was removed to the large hall of the observatory, where, enclosed in two wooden cases, it was placed in a niche cut in the pier of the ten-inch refractor. To further guard against sudden changes of temperature the niche is closed by a glass door. At the meeting of the Royal Academy of Sciences at Amsterdam, held September 27, 1902, Dr. E. F. van de Sande Bakhuyzen submitted the following formula as the best representation of the daily rate of the clock:

$$\text{Daily rate} = -0^s.173 + 0^s.0157(h-760^{mm}) - 0^s.0253(t-10°) + 0^s.00074(t-10°)^2 + 0^s.0465 \cos 2\pi(T-\text{May } 3)/365$$

and gave the result of a comparison of the observed daily rates 1899–1902, the average interval of time for each rate being six

days, with those computed by means of the above formula. I find during the year 1900 the mean of these difference is $0^s.028$ and the largest difference is $0^s.071$.

About 1867 F. Tiede installed at the Berlin Observatory a weight-driven clock enclosed in an air-tight case. The original escapement was replaced in 1876 by a gravity escapement and the clock has continued to give satisfaction, certainly up until 1902, when it was dismounted for cleaning. The only published rates that I have been able to secure are those during twelve weeks in 1877–8. During this period the average deviation of the observed daily rates, the average interval for each rate being six days, from the mean daily rate for the entire period is $0^s.030$.

In connection with the publication of these rates[2] the statement is made that for weeks at a time this mean deviation will not exceed $0^s.02$.

DAILY RATE OF RIEFLER SIDEREAL CLOCK NO. 70.

Date	Daily Rate	Mean Barometer	Mean Temp.	Computed Rate	O—C.
1904	s.	mm.	°	s.	s.
Feb. 8–11	+0.019	631.0	28.3 C.	+0.009	+0.010
11–15	—0.014	631.5	28.5	—0.006	—0.008
15–20	+0.005	631.5	28.3	—0.002	+0.007
Mar. 1– 4	—0.026	631.0	28.2	—0.012	—0.014
4– 9	—0.010	631.0	28.2	—0.016	+0.006
9–16	—0.022	631.5	28.1	—0.018	—0.004
16–18	—0.043	631.0	28.1	—0.022	—0.021
18–22	—0.022	631.0	28.0	—0.021	—0.001
22–25	—0.029	631.0	28.0	—0.024	—0.005
25–28	+0.002	631.0	27.7	—0.014	+0.016
28–34	—0.007	631.0	27.7	—0.018	+0.011
Apr. 3– 5	+0.017	631.0	27.4	—0.009	+0.026
5–13	+0.002	631.0	26.9	+0.014	—0.012
13–16	+0.026	631.0	26.5	+0.021	+0.005
16–19	+0.034	631.0	26.3	+0.027	+0.007
19–22	+0.002	631.0	26.4	+0.020	—0.018
22–31	+0.029	631.0	25.0	+0.077	—0.048
May 1– 4	+0.113	631.5	24.3	+0.103	+0.010
4– 7	+0.082	631.0	24.1	+0.109	—0.027
7–12	+0.161	631.0	24.0	+0.109	+0.052
				Mean	±0.015

In 1903 there was installed at the Naval Observatory one of Riefler's clocks, No. 70, with a nickel-steel pendulum, the impulse being communicated to the pendulum through the suspension spring. This clock was enclosed in an air-tight glass case and was mounted in a vault where the temperature was artificially controlled. The definitive rates have been determined from September, 1903, to May, 1904, but, unfortunately, during this entire period we were unable to prevent the glass case leaking and there was a variation of temperature in the vault of about 5° C. However, from the first of February to the middle of May the pressure was kept nearly constant by reducing it each day by means of an air pump by from 1 to 2 millimeters. During this period the following results were obtained:

The formula from which the computed rate is obtained,

$$\text{Daily rate} = +\,0^s.0161 - 0^s.00103\,(T\text{–Mar. }29.0) - 0^s.0456\,(t - 27°.0)$$

is the result of a least square solution of the twenty observed rates.

Collecting together the results given above, we have:

MEAN DEVIATION OF DAILY CLOCK RATE.

Clock	Date	Mean Deviation
Bradley	1759	0.102
Greenwich Observatory	1850	0.149
Greenwich Observatory	1900	0.051
Berlin Observatory	1877	0.02–0.03
Leiden Observatory	1900	0.028
U. S. Naval Observatory	1904	0.015

In considering this table I hope the particular method by which each of the numbers given was obtained will be remembered. The reason for using different methods has already been given. If the rates of the first three clocks had been treated in a manner similar to that used in the last three cases, the numbers given might have been slightly smaller, and if the period under consideration with the Berlin and Washington clocks had been

[2] A. N. Nr. 2184.

longer the two corresponding residuals might have been slightly larger.

W. S. EICHELBERGER

U. S. NAVAL OBSERVATORY

THE NEW YORK MEETING OF SECTION C OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE AND THE THIRTY-FIFTH GENERAL MEETING OF THE AMERICAN CHEMICAL SOCIETY—II.

BIOLOGICAL CHEMISTRY

Wm. J. Gies, Chairman

The Rational Conversion of Energy: J. E. SIEBEL, JR.

The Thermodynamics of Nutrition: J. E. SIEBEL, JR.

The Effects of Magnesium Sulphate upon Seedlings: GERTRUDE BURLINGHAM.

From extended experiments upon the growth of seedlings in dilute solutions of magnesium sulphate, it was found that while it is usually toxic in strengths greater than $M/8192$ (0.003 per cent.), it produces decided stimulation in $M/16384$, reaches a maximum stimulation at dilutions from $M/32768$ to $M/131072$ (0.00075 per cent. to 0.00018 per cent.), then beyond this point gradually diminishes in action. The point of toxicity and of greatest stimulation varies with the type of seedling. Both the plumule and the roots attain greater growth in these favorable dilutions of magnesium sulphate and in the control of distilled water, and often the lateral roots develop two or three days sooner. While growth in the control practically stops at the end of one week, it continues from four to five weeks in the magnesium sulphate cultures. Two parallel series, one magnesium sulphate and control, the other calcium nitrate and control, in dilutions from $M/8192$, $M/16384$, etc., to $M/262144$, showed that calcium ceases to be stimulating in the dilution in which magnesium loses its toxicity and produces maximum stimulation; in $M/32768$ magnesium sulphate the root growth is eight times that in calcium nitrate. In every instance after the renewal of the solutions, growth was accelerated in the magnesium cultures, while there was little change in the control. Seedlings allowed to grow for several weeks in a dilution of magnesium sulphate which was at first slightly toxic, finally developed strong lateral roots and attained a root growth far beyond the control. These results show conclusively that magnesium sulphate in proper dilution is beneficial to the growth of seedlings, and that any inhibitory effects are due to the presence of excessive amounts, thus controverting Loew's theory that magnesium salts when alone in solution are always injurious to plant growth.

Chronic Arsenical Poisoning and the Distribution of Arsenic in the Animal Organism: WM. D. HARKINS.

In copper smelting regions arsenic is likely to be a constituent of grass, hay, and all the organs of animals. Grass has been found to contain as high as 1,500 parts of arsenic trioxide, and the ulcers in the noses of horses as high as 1,000 parts per million. 0.362 Gram of arsenic trioxide killed a sheep in eight days, 0.123 gram of sodium arsenite killed a sheep in thirty-three days with thirty-one pounds loss of weight, and 0.055 gram in sixty-nine days with ten pounds loss in weight.

On Proteose Fever: R. B. GIBSON.

Fever has been considered to result from the injection of prepared proteoses and of bacterial endo- and extra-cellular proteose-like substances, especially as albumosuria is often observed in septic and aseptic fevers of experimental or natural origin. As yet no observations have been made with proteoses prepared from highly purified or crystalline proteids. Pepsin-HCl